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Rectangular active microstrip patch antennas : few experimental observations

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Abstract : This paper gives an experimental verification of a recent work by the authors to verify the location of the active device on the microstrip patch antenna for the highest possible radiated power. At the patch design frequency location (l_1) of the device on the patch has been found theoretically for the highest possible radiated power by considering a modified transmission line model and device-antenna non-linear interaction. Experimental results show very good agreement with theory. Patches are designed at two frequencies of 9.5 GHz and 9.0 GHz and an X-band 50 mW Gunn diode is used as an active device. Diode placed at the desired location, power output of the active antenna is 64.0 mW and its dc-to-RF conversion efficiency is almost comparable to that of its waveguide tuned version. Due to proper matching of the device and antenna impedances, radiation pattern of the active antenna improves greatly in addition to the lowering of its cross polarisation level

Keywords Microstrip antennas, observations

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1. Introduction

Typical requirements of conventional microwave systems like radar, missile guidance and communication equipments are large amplifiers to produce high power beam, waveguide for its low loss and high power capabilities and motors for scanning the antenna main beam. But all these components are bulky, occupy large space and not very easily routed. Most efficient replacements have been found in the active antenna array [1] where active devices are integrated directly into the antenna platform.

Rectangular microstrip patches (potentially the most attractive candidate for antenna phased arrays) integrated with two terminal active device like Gunn diode or three terminal MESFET devices very well serve the purpose of radiating antenna which is called an active antenna or quasi-optical transmitter. Number of such antennas may be integrated to form an array for generating high power main beam which can also be electronically scanned or steered [2-4]. As a matter of fact, the number of publications on photonic beam forming [5] and non-mechanical steering [6] for this kind of arrays are increasing rapidly day by day.

Secondly, individual radiation patterns obtained were irregular having high cross-polarisation levels (CPL) which reduces radiation efficiency and usefulness of the antenna. Hence, it was felt to the authors that the design of rectangular active microstrip patches were not properly addressed. Based on accurate transmission line model and considering device antenna non-linear interaction, a more exact diode placement location was given [7] by the present authors for the highest possible radiated power. In this paper, experimental verification to support the theoretical results as presented in [8] has been performed. The diode is placed at different locations into the antennas along with the desired location and the performance of those antennas like its power output, frequency and purity of the spectral output, radiation pattern etc. are measured.

2. Design of active antenna

Figure 1a shows the configuration of the active antenna. A Gunn diode, that serves the purpose of an active device, is integrated to rectangular microstrip patch. The resonant frequency of the rectangular patch in the dominant TM_{10} mode is [9,10]

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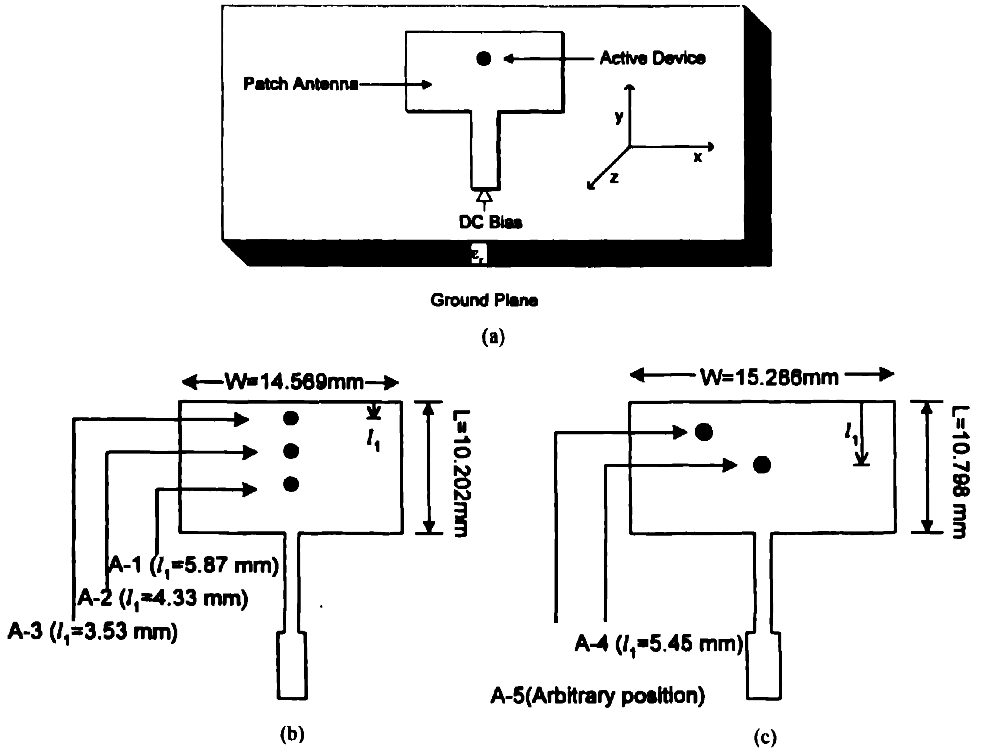

Figure 1. (a–c)

$$f_r = \frac{c}{2\sqrt{\varepsilon_r}}\left(\frac{1}{L}\right) \tag{1}$$

L is the length of the patch, ε_r is relative dielectric constant and c is the velocity of light. This result however ignores the fringing field effect at the patch edges. So a correction factor is applied [9] to obtain accurate patch dimension for a particular resonant frequency. However, placement of a pill type diode in the patch alters the resonant frequency. Hence a deviation in the operating frequency of the active patch antenna is often found from its design frequency [11]. Using a modified transmission line model [8], the input conductance (G_{in}) and the maximum radiated power ($P_r|_{max}$) of the active patch were deduced as a function of diode placement location (l_1) as follows :

$$G_{in} = \left[2G + 0.5(G_i + R_1 Y_0^2)L\right]\sec^2\left(\pi\frac{l_1}{L}\right), \tag{2}$$

$$P_r|_{max} = \frac{16G_r^2}{3\gamma}\sec^2\left(\pi\frac{l_1}{L}\right), \tag{3}$$

$$l_1 = \frac{1}{\pi}\cos^{-1}\sqrt{\frac{1}{G_d}\left\{4G_r - 2G_m + 0.5(G_i + R_1 Y_0^2)L\right\}}. \tag{4}$$

G denotes the total patch conductance with G_r and G_m are radiation and mutual conductances respectively, G_i is the intrinsic conductance, R_1 is the intrinsic resistance, Y_0 is the characteristic admittance, G_d is the diode conductance and γ is the non-linear diode constant. Values of the different antenna parameters were taken or calculated as in [9,10] Eq. (3) gives the value of maximum radiated power for the diode position l_1 as given in eq. (4).

3. Experimental observation and discussion

Two sets of five patch antennas are fabricated at two spot frequencies (f_r) of 9.0 GHz and 9.5 GHz by using 0.787 mm thick Takonic TLY-5-0310-CH/CH substrate with ε_r = 2.2 At the two frequencies, length of the patches are calculated as 10.7988 mm and 10.2024 mm. Taking the diode dynamic impedance approximately as 10 Ω, the optimum position (l_1) is calculated as 4.33 mm at a frequency of 9.5 GHz. On the similar two other patches, diodes are placed at two other locations of 5.87 mm and 3.53 mm. For the other variety (f_r = 9.0 GHz), it is placed at the patch centre (l_1 = 5.45 mm) and at an arbitrary location neither of which is the optimum location (l_1) to give highest power. The entire scheme is shown in Figures 1b and 1c where the diode locations have been measured from the top edge of the patches. Gunn diode which serves as the active device is a commercially available MA-COM X-band 50 mw packaged Gunn diode (MA 49106). To get a comparative picture, same diode is used for all the five patches. The results are given in Tables 1–3.

Table 1. Calculated and measured operating frequencies for two set of patch antennas.

Antenna	l_1 (mm)	Calculated f_r (GHz)	Measured f_r (GHz)	% Error
A-1	5.87	9.5	9 77	2 84
A-2	4.33	9.5	9.76	2.74
A-3	3.53	9.5	9 646	1.54
A-4	5.45	9.0	9 036	0.34
A-5	arbitrary location	9.0	9.82	9.11

Table 2. Measured active antenna power at the operating frequencies

Antenna	Operating Frequency (GHz)	Bias voltage (V)/ Current (mA)	Oscillator Power (mW)*	EIRP (mW)
A-1	9.77	12.64/381	29.8	186 83
A-2	9 76	11.90/390	35.9	225 10
A-3	9.646	11.10/420	64 33	403 6
A-4	9 036	11.00/303	1.0	6 14
A-5	9 82	10 70/322	2 57	16.10

* Calculated using a passive antenna gain of 7.97 dBi [9].

Table 3. Efficiency of the active antennas in comparison to its waveguide

Operating frequency (GHz)	RF Power (mw) in w/g cavity	RF Power (mw) in patch	dc-to-RF conversion efficiency (%) in w/g cavity	dc-to-RF conversion efficiency (%) in patch
9 77	64 10	29 80	1.42	0 62
9 76	50.35	35.90	1.17	0.77
9 646	63 10	64.33	1 55	1.38
9 036	55.60	1.00	1 42	
9 82	47 21	2.57	1 18	

Tables 1 and 2 list the operational parameters of the antennas like frequency, power *etc*. For the patches A-1 to A-4, diode has been placed at the points $(W/2, l_1)$, where W is the width of the patch. For the patch A-5, the position of the diode on the patch is arbitrary (x, y). It is found from Table 2 that patch 'A-3' (l_1 = 3.53 mm) gives the highest radiated power though the position of the diode on the patch should be l_1 = 4.33 mm (patch A-2). Diode position on patch A-1 is the conjugate to that of patch A-3 [8]. Offset in the diode placement location (l_1) for the highest possible radiated power may be attributed to the facts as below.

(i) Above exercise is based on the assumption that the diode is a point source. But in practice, it is not so. Analysing an equivalent tuned circuit model of the patch [13], it is seen that the value of l_1 for which fundamental power is maximum, is very close to the point at which second harmonic maximum occurs (Figure 2). When the diode is placed at the point (l_1 = 4.33 mm), it infringes into the susceptible zone of second harmonic oscillation. This may cause a significant reduction of the fundamental power. To have highest fundamental power output, the suggested equation for locating the diode position is

$$l_1|_{new} = l_1 - \text{diode cap diameter}/2,$$

where the diode cap diameter for the type of Gunn diode used here is around 3 mm.

(ii) Precise value of the diode dynamic conductance chosen to calculate l_1.

(iii) Manufacturing and other tolerances associated with patch antenna itself.

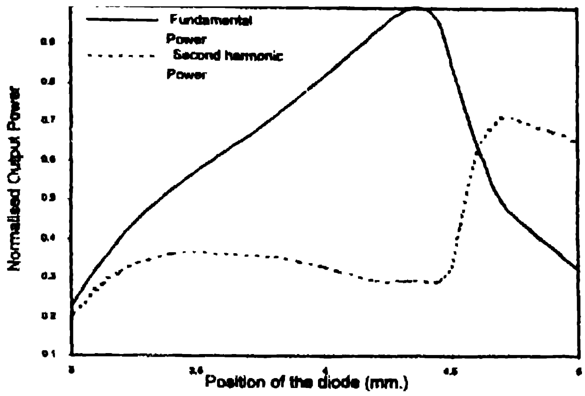

Figure 2.

Figure 2 also explains the low power output of the patch antenna A-1. When the diode is placed further up (l_1 < 3.53 mm), radiated power is found to decrease along with significant deviation in the operating frequency (f_r). It can also be noted from the above data that a little shift from the exact location on the patch reduces the RF power to a large extent.

The frequency error is only 1.54%, which signifies that the operating frequency is almost same to the design frequency (f_r). Hence, the frequency error is much lower in comparison to as reported earlier [12] for circular stripline patches. dc-to-RF conversion efficiency of the antenna for the highest possible radiated power is almost comparable to the waveguide tuned oscillator (Table 3).

Radiation patterns are measured for three antennas, namely, A-3, (active patch that offers the best performance), A-5 (active patch with arbitrary diode location) and a passive patch. Radiation patterns are measured in free space (more specifically in laboratory environment) which are given in Figures 3 and 4. A comparative picture is also vivid from the two figures for both E-plane and H-plane patterns. Proper placement of the diode in the patch not only improves its radiation efficiency, but also removes the irregularity. Additionally, lowering in cross polarisation level (CPL) occurs which was supposed to be one of its drawbacks [10]. Normally, the insertion of solid-state device into a patch antenna disturbs the fields within the antenna cavity, which causes a large deviation in the antenna radiation pattern. However, the approach as reported by the authors [8], offers very encouraging results compared to the others as verified

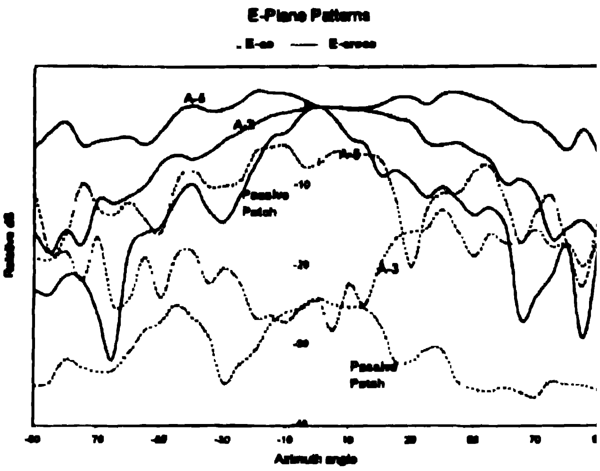

Figure 3.

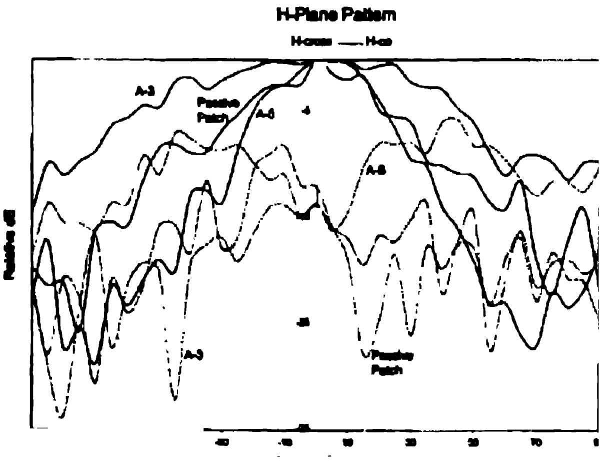

Figure 4.

experimentally in this paper. Spectral purity of the radiated spectrum is observed to be almost comparable to that of a waveguide tuned oscillator.

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